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GUIDE

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Recommendations for the implementation of harmonised air quality measurements within underground railway stations

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This methodological guide was developed at the request of the DGPR (General Directorate for Risk Prevention) within the Ministry of Ecological Transition and Territorial Cohesion.

It was based on feedback from a working group steered by the DGPR and involved several rail operators, organizing authorities and ministries, as well as Ineris. Trials were also conducted with four French rail operators to test several parts and clarify its implementation. This guide has been reviewed by this working group.

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Contents

1 SUMMARY

This guide provides recommendations for carrying out harmonised air quality measurements within underground railway stations (URS). The main purpose of this guide is to acquire data on the air pollution levels that can be observed in URS, based on a joint approach that is subject to the consensus of a working group presided over by the Ministry of Ecological Transition and Territorial Cohesion, which brings together several rail operators, organising authorities, ministries and Ineris.

The measurements cover the air in underground railways platforms and rolling stock. The measurements concern the atmosphere of underground platforms and the passenger compartments of the trains that serve them. They aim to characterise the concentration levels of certain pollutants to which passengers are exposed, mainly PM_{10} and $PM_{2.5}$ particles, and the metals present in PM_{10} particles. The measurement of CO_2 has also been incorporated into the sampling plan as a confinement indicator in relation to air renewal, temperature and relative humidity (to identify atypical situations in terms of passenger comfort). A summary of these measurements is given in Table 1.

Recommendations concerning different aspects:

- data to be collected prior to and during the measurement campaigns;
- selection of the platforms to be equipped with instruments, the related measurement strategy and the data presentation format;
- selection of the trains to be equipped with instruments, the related measurement strategy and the data presentation format.

This methodology is not intended to meet the objective of continuous air quality monitoring, or the search for sources of pollution.

	Scope of the measurements	Parameters measured	Location of the measurements	Period, duration and frequency of the measurements			Results obtained
Measurements on underground platforms	After the selection phase for the platforms to be equipped with instruments, measurements are carried out at least on those platforms with the highest PM_{10} concentrations and the heaviest passenger traffic.	PM_{10} and $PM_{2.5}$ particles Metals in PM_{10} Confinement (CO_2) Comfort parameters (T°C and RH)	At the centre of the platform Between 0.8 and 2.0 m above the ground	Excluding school holiday periods	Continuous PM_{10} measurements over one week (W1). Continuous $PM_{2.5}$ measurements over one week (W2). Integrative filter measurements of PM_{10} and PM_{10} metals over 14 days: 1 sample per day, from the first train to the last (during daily business hours).	Updated at least once a year.	**Per platform studied:** Continuous measurements of the concentrations of PM_{10} and $PM_{2.5}$ particles and CO_2 over 14 days. 14 integrated measurements over 24 h of the concentrations of PM_{10} particles and PM_{10} metals.
Measurements inside the railway rolling stock.	Measurements are carried out in each type of train on each line whose underground travel time is greater than 25% of the journey over the entire line.	PM_{10} and $PM_{2.5}$ particles Metals in PM_{10} Confinement (CO_2) Comfort parameters (T°C and RH)	In the centre of the central train Between 0.8 and 2.0 m above the ground	During peak periods Excluding weekends, public holidays and school holidays.	At least 1 measurement over 1 to 2 hours at least during the return trip from the beginning to the end of the line over 3 different days, whether consecutive or not.	Depending on the size of the network, all lines with underground platforms will be covered in 1 to 3 years.	**Par rame étudiée :** 3 mesures en continu des particules PM_{10} et $PM_{2,5}$, et de CO_2 du début jusqu'à la fin de la Line. 3 mesures intégrées de PM_{10} et $PM_{2,5}$ et de métaux sur PM_{10} au minimum lors d'un aller/retour du début jusqu'à la fin de la Line.

Table 1: Summary of the requested measurements

2 CONTEXT AND OBJECTIVES

Underground railway stations (URS) can be defined as "all covered areas situated below ground level connected to an underground rail transport track"[1]. Seven metropolitan areas have URS in France: Lille, Lyon, Marseille, Paris, Rennes, Rouen and Toulouse.

These networks have different configurations, ranging from small networks with a single rail line and around thirty overground and underground stations to larger networks with more than ten lines and over three hundred stations. The number of underground stations is also variable.

	Number of stations*	Number of lines with at least one underground station	Proportion of underground stations per line (in %)
RATP Paris	309 stations and 66 RER stations	16 lines (14 metro lines and 2 RER lines)	54 to 100% for metro lines
SNCF Paris	392 stations in Ile-de-France including 33 in Paris (stations and halts combined)	6 lines	with 12 lines > 80% 20 to 50% for RER lines
KEOLIS Lyon	42 metro stations	5 lines	11 to 32% for RER lines
RTM Marseille	30 metro stations	2 metro lines and 1 tram line	> 90%
KEOLIS Rennes	15 metro stations	2 lines	> 85%
TCAR Rouen	31 metro stations	1 line	87%
TISSEO Toulouse	37 (including one shared by Lines A and B) 21 for the third line	2 lines *(1 line in 2028)*	16%

*Several stopping points may exist per station depending on the number of connections.

Table 2: Example of some railway networks in France

1. Anses report "Pollution chimique de l'air des enceintes de transports ferroviaires souterrains et risques sanitaires associés chez les travailleurs", 2015.

The air quality in underground railway stations (URS) that serve passenger trains is not subject to regulations, as it is in certain public-access buildings (PAB).[2] However, air quality in URS and its potential impact on the health of persons exposed to it has become a subject of concern for many years. Thus, in 2000, the CSHPF (the Higher Council of Public Health of France) issued several notes[3, 4, 5, 6, 7, 8, 9] concerning this subject. In May 2001, it defined reference values for PM_{10} air quality in URS, intended for users of public transportation. These values were based on four scenarios corresponding to four typical durations of daily travel in underground railway areas (durations varying from 1h30 min to 2h15 min). It also issued a recommendation that rail operators intensify their actions to identify the sources and reduce the levels of particulate matter and requested them to establish a multi-year plan to reduce particulate pollution in URS. In addition, it recommended that SNCF and RATP implement sustained monitoring of PM_{10} concentrations in the underground railway areas of Ile-de-France.

In 2003, the ministry in charge of public health published circular DGS/SD7B no. 2003-314 of 30 June 2003 relative to air quality in URS. In this circular, the director general of health requested that the operators of underground public transport apply the CSPHF recommendations by defining a plan to monitor air quality and identify the sources of pollutants in order to define a strategy for reducing emissions.

An analysis of the CSHPF recommendations was conducted in the context of appraisals by ANSES concerning the relevance and feasibility of the development of specific indoor air quality guidelines (IAQG) for user exposure in URS published in 2022 (referral 2019-SA-0148). It underlines that the pollution that is best characterized, and which is responsible for the highest daily overexposure is that measured by the mass concentration of particulate matter (PM_{10} and $PM_{2.5}$). It highlights the lack of sufficient data to develop specific indoor air quality guidelines (IAQG) for air pollution in URS in compliance with Anses methodology (Anses, 2016). This could be explained by the absence of a WHO-proposed guide value and Toxicity Reference Values (TRV) and considering epidemiological and toxicological studies corpus that does not allow to identify a toxicological or epidemiological starting point (POD) in relation to harmful health effects. Moreover, it observes that « the corpus of studies suggests the possibility of effects on cardiac autonomic function, systemic inflammation and oxidative stress, as well as inflammation of the respiratory tract, particularly among sensitive populations such as asthmatics ». In this context, Anses "considers that the method proposed by the CSHPF in 2001 for the construction of specific management values for URS in relation to user traffic remains relevant. Indeed, it ensures that users frequenting URS do not exceed the regulatory daily values established for ambient air ». However, in this new analysis of the data, Anses has made a number of changes to the values recommended by the CSHPF that integrate the WHO PM guide values (2021[10]) in addition to the regulatory values for ambient air quality, recent measurement data and a change to the agreed exposure scenarios. Finally, Anses recommends, at least not to exceed PM_{10} and $PM_{2.5}$ concentrations in the air of URS based on the WHO guidelines values (2021) for ambient air quality (CUnd_WHO), and even more importantly, not to exceed PM_{10} concentrations in the air of URS calculated from the daily limit value of European Directive 2008/50/EC for PM_{10} in ambient air (Cund_Lim) (Table 3).

The conditions of application specified by Anses must be considered when using these values (Anses, 2022[11]).

2. Article R. 221-30 et seq. of the Environmental Code and the related regulatory texts.
3. CSHPF – Note of 10 October 2000 concerning air quality in underground railway areas.
4. CSHPF – Note of 5 April 2001 concerning air quality in underground railway areas.
5. CSHPF – Note of 3 May 2001 concerning the development of air quality guidelines for underground railway areas.
6. CSHPF – Note of 8 July 2003 concerning new recommendations for the operators of underground rail networks, RATP in particular.
7. CSHPF – Note of 12 May 2005 concerning new recommendations for operators of underground rail networks concerning pollution on the RATP network.
8. CSHPF – Note of 12 May 2005 concerning new recommendations for operators of underground rail networks, SNCF in particular.
9. CSHPF – Note of 27 September 2006 concerning air quality in transport.

10. OMS. 2021. «WHO global air quality guidelines. Particulate matter ($PM_{2,5}$ and PM_{10}), ozone, nitrogen dioxide, sulfur dioxide nad carbon monoxide.» Licence: CC BY-NC-SA 3.0 IGO: Organisation Mondiale de la Santé (OMS). 1-267.
11. Anses, 2022 Anses opinion on the state of knowledge on the toxicity of particulate matter and the health effects associated with air pollution in underground railway stations (URS) and to the the proposal for particle concentrations in the air of URSs not to be not to be exceeded ('Saisine 2019-SA-0148').

Ineris assisted the Ministry of Ecological Transition and Territorial Cohesion in developing, in concertation with various rail operators, a guide of recommendations for harmonised measurements of air quality in URSs. This guide corresponds to a minimum basis for the acquisition of measurement data via a joint approach in order to:

- consolidate the characterisation of the existing air quality in the various URS, by specifying the pollutants to be monitored, the related measurement strategies and data presentation formats;
- monitor changes in the concentration levels through periodic campaigns associated with data exploitation conditions;
- develop and share feedback at the national level based on measurement data collected according to the same methodology.

The measurements covered the air in underground platforms and in the rolling stocks of underground trains. They aim to characterise the concentration levels of certain pollutants to which passengers are exposed. Experiments were conducted with four French rail operators to test several aspects and clarify its implementation (Appendix 9).

This guide is not intended to meet the objective of continuous air quality monitoring or the search for sources of pollution.

Throughout the document, the word "platform" will specifically refer to platforms located in underground railway stations (URS). It includes the two platforms associated with the two directions of the line serving a station.

Pollutant	Cumulative time spent in URS for one day	Concentration calculated from the daily limit value of European Directive 2008/50/EC* ($\mu g.m^{-3}$) (Cund_Lim)	Concentration calculated from the daily guideline value of the WHO (2021)* ($\mu g.m^{-3}$) (Cund_WHO)
PM_{10}	2h	260	80
	1h30	330	100
	1h	480	140
	30 min	940	250
$PM_{2,5}$	2h	n.a.	50
	1h30	n.a.	60
	1h	n.a.	80
	30 min	n.a.	140

Table 3: Minimum recommended particles concentration in URS (Anses, 2022)

3 CRITERIA FOR SELECTING POLLUTANTS TO BE MEASURED

The study of two reports[12] has made it possible to identify the main pollutants encountered in the air in URS. These reports provide data based on extensive literature review, compiling data from French and international studies. The summary of the data from these two studies is available in Appendix 1.

For the key pollutants studied in the URSs, Appendix 2 presents the CSHPF opinions on air quality in URS and the related existing management values for indoor air. For ambient air (or outdoor air), an environmental objective defines the state of the air quality that must be respected on a given date, or, as far as possible, over a given or long-term period, in compliance with Article R. 221-1 of the Environmental Code.

The current environmental objectives per pollutant are updated annually and are available at https://www.lcsqa.org/fr/objectifs-environnementaux.

Based on this data (Appendix 1 and Appendix 2), a list of pollutants of interest to be measured has been identified. The flowchart presented in Figure 1 details the selection criteria.

The normative references and guidelines associated with the measurement of all pollutants of interest (lists P1 and P2) are presented in Appendices 3 and 4.

12. Dorothée Grange and Sabine Host "Pollution de l'air dans les enceintes souterraines de transport ferroviaire et santé", Observatoire régional de santé Île-de-France, June 2012.

Rapport Anses « Pollution chimique de l'air des enceintes de transports ferroviaires souterrains et risques sanitaires associés chez les travailleurs », 2015.

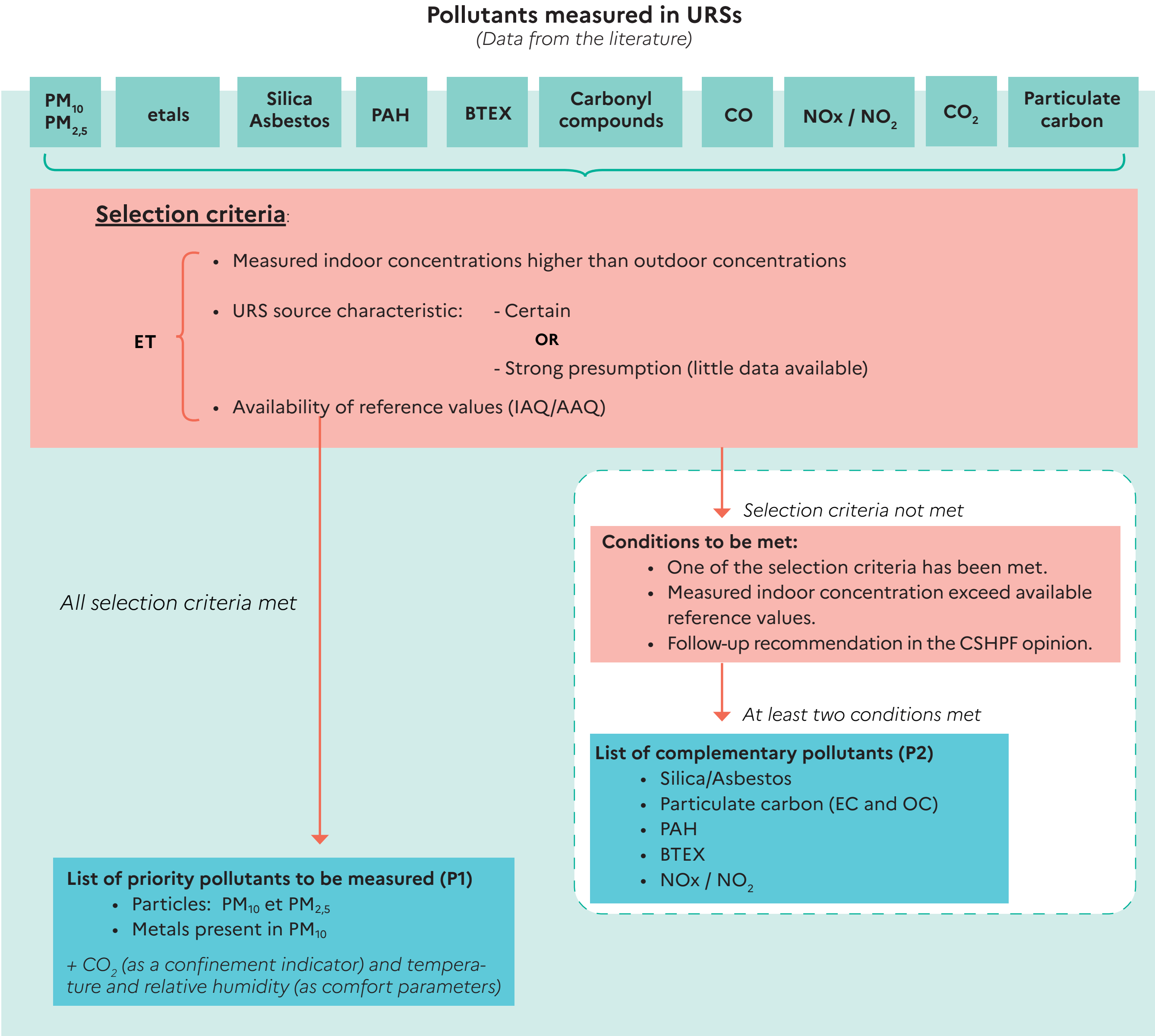


Figure 1: Flowchart for selected pollutants of interest to be measured

4 RECOMMENDATIONS FOR TAKING THE MEASUREMENTS

This guide only describes the measurement strategy for priority pollutants (P1):

- particles: PM_{10} and $PM_{2.5}$
- metals present in PM_{10} particles: iron (Fe), barium (Ba), copper (Cu), zinc (Zn), antimony (Sb), manganese (Mn), nickel (Ni), lead (Pb), arsenic (As), cadmium (Cd) and chrome (Cr).

During these campaigns, CO_2, temperature, and relative humidity should also be measured in order to identify atypical situations in terms of ventilation or passenger comfort.

The reviewed reports indicate that particulate concentration levels are the highest at the level of the platforms, given their proximity to the trains and associated sources of emissions: friction and abrasion via the braking systems, electrical power supply systems, rail-wheel contact, re-suspension of deposited dust, etc. According to several French rail operators, the levels observed in the corridors and transit halls are essentially related to the transfer of pollution from these sources.

Nevertheless, it should be noted that this ranking does not take into account the time spent by travellers in these different areas.

The recommendations concern different aspects:

- The data to be collected prior to and during the measurement campaigns;
- The selection of the underground platforms to be equipped with instruments, the related measurement strategy, and the data reporting format;
- The selection of the trains to be equipped with instruments, the related measurement strategy and the data reporting format.

4.1 Data to be gathered

Various operational, passenger traffic and ambience parameters should be recorded prior to the measurement campaigns. The collection of this data is important in order to develop the sampling plan and to best interpret the results of the measurements. Some parameters should also be recorded specifically during the measurement campaigns (such as passenger traffic on the platforms or in the stations and aboard the trains, the conditions of circulation and of the rolling stock, and the frequency or intervals of the passage of trains).

Characteristics of the rolling stock (per line)	**Passenger traffic, conditions of circulation** (per line and per station)	**Platform characteristics**
• **Rolling stock used:** type (Metro/RER/tram), model, whether or not a compartmentalised vehicle, single- or double-deck, equipment, weight of rolling stock with passengers. • **Power source:** via rails or catenaries. • **Type of wheels:** tyres, iron. • **Braking and steering system:** electrodynamic, mechanical braking, braking materials.	• **Number of passengers** in the train per day or entries into the station over the year and during the measurement period. • **Traffic conditions:** train frequency (frequency/interval), frequency during peak and off-peak hours, extent of business hours, disturbances during measurements (unplanned stoppages, unscheduled works, etc.).	• **Configuration:** depth, volume, existence of a curve in the track before or after the platform for the two adjacent stations, presence of platform screen doors. • **General ventilation of the station, platform and adjacent tunnels:** natural ventilation, mechanical ventilation (maintenance/flow rate). • **Connections:** existence of connections on the same platforms, on different platforms (overlapping networks). • **Number of tracks at the platform.**

Table 4: Activity and operating parameters to record

4.2 Platform measurements

4.2.1. Selection of the platforms to be equipped with instruments

Identification of the platforms on which regular measurements will be taken is based on prior studies of the particulate concentration levels encountered on the platforms during normal network operation.

Depending on the size of the network, the selection criteria for the platforms will be applied either to a representative sample of the network with respect to the various factors that influence the levels of particulate concentration, or to its totality. These sets will comprise the platform bases to which these criteria will be applied.

4.2.1.1. Determination of the platform base

It is proposed that one of the following two approaches be preferred depending on the size of the network. It will be assessed by the number of stopping points that are each defined by the station and the line that serves it.

4.2.1.1.1. The case of large networks: statistical study

For underground networks with more than 50 stations, the selection criteria will be applied to a sample of platforms whose representativity to the different types of platforms in the network in terms of PM_{10} concentrations has been demonstrated by prior statistical studies based on measurement campaigns results. These criteria will consider all the factors that might influence particle levels (characteristics of the rolling stock, platforms and operating conditions), but for which the result of their combinations is complex to determine.

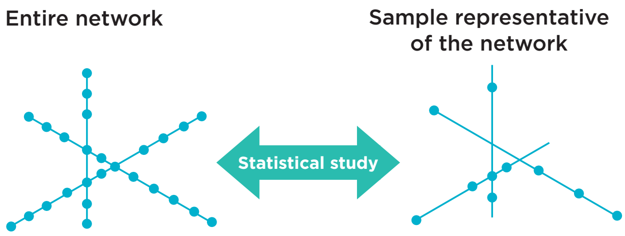


Figure 2: Example of a platform sample, confirmed by a statistical study as being representative of various platform typologies of a large network.

The statistical study should be described and, for each of the platforms in the sample that is considered representative of a type of platform in the network, the average concentrations of PM_{10} shall be presented as follows:

Line	Station	Location of the sampling system (centre of the platform, other: specify)	Sampling height (in metres)	Date of study	PM_{10} (µg/m^3)

4.2.1.1.2. The case of small networks: systematic mapping

For networks consisting of a maximum of 50 stations, the ranking is based on a complete mapping of PM_{10} concentrations measured across all platforms.

Measurement methods

PM_{10} mapping must be performed using portable instruments (optical methods) that provide an indicative measurement of particle concentrations in the air[13].

These methods cannot substitute for the referential gravimetric method, but they provide an estimate of the levels and enable reliable comparisons to be made between the values obtained for different points. They can thus provide an initial ranking of concentration levels on different platforms within a network. During these campaigns, measurements of CO_2, temperature and relative humidity should also be performed simultaneously with portable instruments to identify atypical situations in terms of ventilation or passenger comfort (see table 4).

In order to ensure the accuracy and reliability of the data collected, it is essential to conduct intercomparisons of the measurement equipment deployed in the ranking campaign. These comparisons should be carried out before, during and at the end of the measurement campaign. For PM_{10}, a one-off comparison of these devices with a reference method and on a platform is recommended. This comparison should be performed over 3 consecutive days, with 24 hours of data acquisition each day.

If possible, the PM_{10} concentration levels measured outdoors during these measurement campaigns should be recorded to improve the interpretation of the results of the measurements in cases of an atypical situation in the urban background.

This will be supported by data from the AASQA network of measurement stations.

Locations of measurement points

Depending on the geometry of the location, measurements will preferably be taken in the centre of one of the platforms of the line under study. Measurements will be taken between 0.8 and 2.0 m above the ground.

To avoid disturbing the circulation of the area and creating potential safety issues, the location may be modified if necessary. However, areas located at the entrance and exit of tunnels should be avoided.

Period, duration and frequency of the measurements

Measurements shall be carried out during peak hours in the morning (between 7 and 9 am) and at the end of the afternoon (between 5 and 7 pm), excluding weekends, public holidays, and school holiday periods. On the same platform, at least 3 measurements of 15 minutes shall be performed over three distinct days (whether or not consecutive), integrating measurements taken in the morning and the afternoon.

Measurement systems implemented		Parameters measured	Duration and frequency of sampling
Principle of the method	Examples of devices		
Optical indicators for the measurement of airborne dust	Grimm® Dust Trak® FIDAS®	PM_{10}	**Measurement period**: several seconds to 1 minute
CO_2: Infrared analyser	Q-TRAK® AdvancedSense IAQ® Class'Air®	CO_2	**Measurement period**: several seconds to 1 minute

Table 5: Details of the measurement systems implemented

13. LCSQA report "Air intérieur – Indicateurs optiques pour la mesure massique des particules dans les environnements intérieurs", December 2008.

Exploitation of the results

The results of the measurements are to be presented as follows:

Line	Station	**Location of the sampling system** (centre of the platform, other: specify)	**Height of sampling** (in metres)	Date	**Time** start/end	**Measurement period** (morning/afternoon)	**PM_{10}** ($\mu g/m^3$)	**CO_2** (ppm)	**Temperature** (°C)	**Relative humidity** (% RH)

In the results report, the summary of the qualitative description of the platforms that have been measured (usual operation and during measurements) must also be integrated in compliance with Appendix 5.

4.2.1.2. Choice and selection criteria

À partir des bases constituées par une des deux méthodes précédentes, les quais sont classés distinctement en fonction de deux critères :

- valeurs moyennes des concentrations en PM_{10} ;
- fréquentation annuelle.

Measurements will be taken on at least three platforms. The two platforms with the highest concentrations of PM_{10} will first be selected from different stations and, if the network allows it, they will be selected on different lines.

Subsequently, the platform with the greatest passenger traffic will then be selected; it will be distinct from the two previous platforms.

Three examples of the classification of PM_{10} concentration levels and data concerning platform traffic are described below to illustrate these choices (Figures 3 to 5).

Example 1:

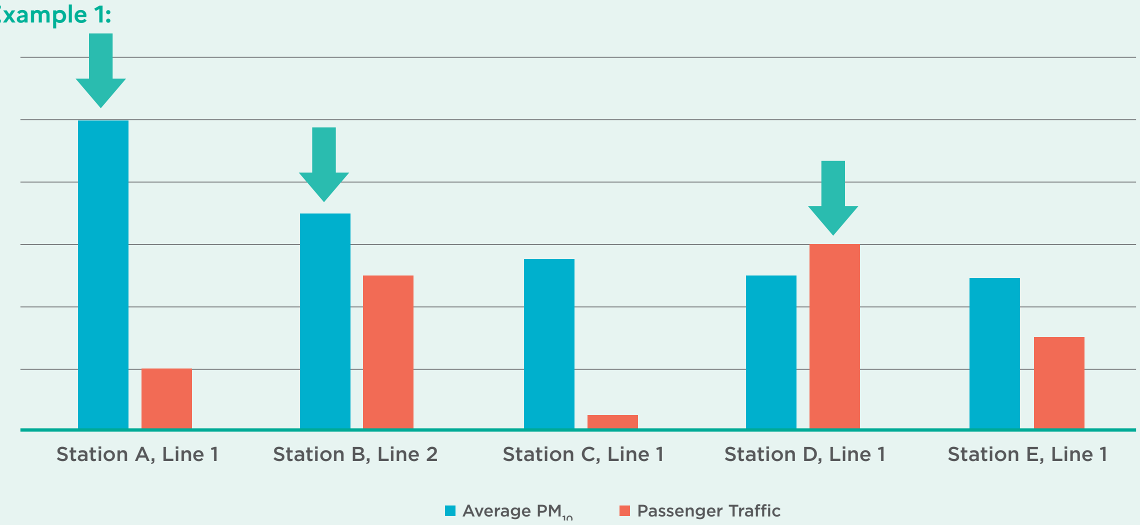


Figure 3: Example 1 of the classification obtained based on prior ranking studies

In this example, the highest concentrations of PM_{10} are observed at platforms A1 and B2, and platform D1 has the highest passenger traffic. Thus, the three platforms to be equipped with instruments are platforms A1, B2 and D1.

Example 2:

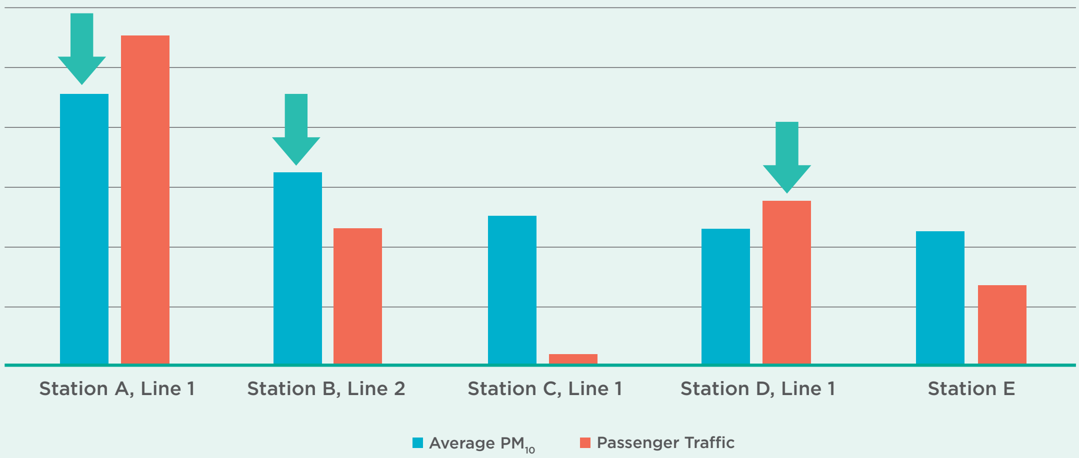


Figure 4: Example 2 of the classification obtained based on prior ranking studies

In this example, the highest concentrations of PM_{10} are measured at platforms A1 and B2, and platform A1 has the highest passenger traffic. However, platform A1 has already been identified as a platform on which measurements should be taken, given its high PM_{10} concentration. Thus, the three platforms to be equipped with instruments are platforms: A1, B2 and D1.

Example 3:

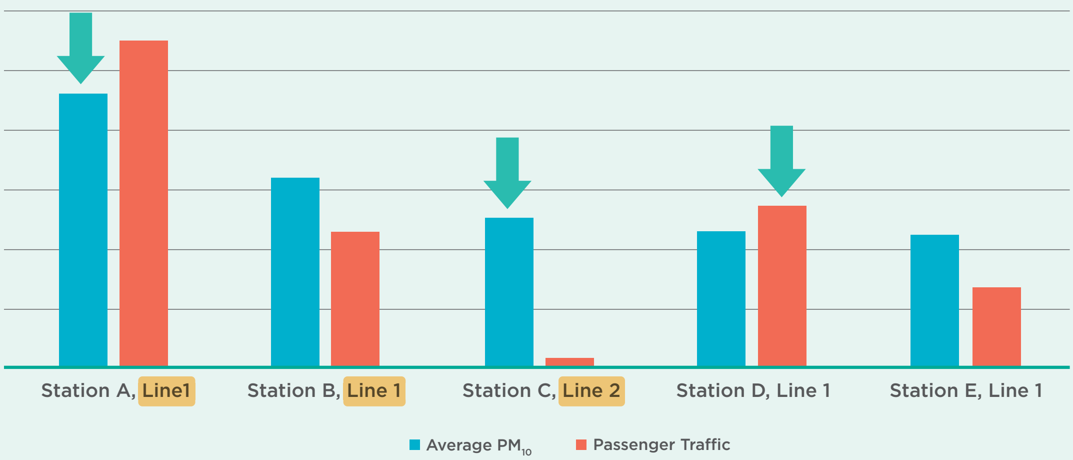


Figure 5: Example 3 of the classification obtained based on prior ranking studies

In this example, the highest concentrations of PM_{10} are measured at platforms A1 and B1, and platform A1 has the highest passenger traffic. Platform B1 is located on the same line as platform A1 (Line 1). In order to ensure the uniformity of PM_{10} measurements across different lines, the three platforms to be equipped with instruments are: A1, C2 and D1.

For the systematic mapping approach preferred for small networks, this classification will be updated annually for the first three years. If this classification remains unchanged, it may be updated every three years; or sooner, in the event of any changes that might have a significant impact on concentration levels.

4.2.2. Measurements on the selected platforms

The regular measurements described below are to be performed on the platforms identified in paragraph 4.2.1. In the case of a platform that is already under continuous or regular monitoring, the need to supplement the existing installation shall be assessed in terms of how adequately the measurement strategy and the data presentation format meet the specifications described below.

4.2.2.1. Measurement strategy

Locations of measurements

Measurements should preferably be taken in the centre of the selected platforms.

Campaign periods, duration and frequency

The measurement period shall be chosen excluding weekends, public holidays, and school holidays (rail traffic may be modified). The measurement campaign shall be performed over 14 consecutive days, at least once per year.

Sampling shall be performed on the platform during business hours.

The time spent by passengers in URS is often short (travel time between 30 minutes and 2 hours and a few minutes of waiting time on the platform). It is therefore necessary to be able to measure particle and metal concentrations within a relatively short period.

Measurement methods

Depending on the measurement methods and according to the available measuring techniques, different sampling frequencies are possible.

Based on the list of priority substances (P1), the following table presents the measurement systems to be implemented and the frequencies and duration of sampling.

Measurement systems implemented		Parameters measured		Duration and frequency of sampling
Principle of the method	**Example of devices**	**1st week**	**2nd week**	
Filter sampling of airborne dust and deferred filter analysis* *(according to reference method NF EN 12341)*	Leckel® DA80® Partisol®	PM_{10} Métaux sur PM_{10}	PM_{10} Metal in PM_{10}	One sample per day. Duration of sampling: from the first train to the last train during daily business hours on the platform.
Automatic airborne dust analyser* *(equivalent to reference method NF EN 12341 according to the recommendations of standard NF EN 16450)*	TEOM® (FDMS not mandatory)	PM_{10}	$PM_{2.5}$	Continuous measurement: 24/7. Measurement period: 15 min.
CO_2, temperature and humidity: InfraRed analyser	Q-TRAK® AdvancedSense IAQ® Class'Air®	CO_2, humidity, temperature	CO_2, humidity, temperature	Continuous measurement: 24/7. Measurement period: 15 min.

*For information, the deployment of measurement systems in the following table may require a ground surface of around 1 m^2.

Table 6 : Details of the measurement systems implemented

If possible, the PM_{10} concentration levels measured outdoors during these measurement campaigns should be recorded to improve the interpretation of the results of the measurements in case of an atypical situation in the urban background that is representative of the platforms studied. This will notably be supported by data from the AASQA network of measurement stations.

4.2.2.2. Exploitation of the results

Depending on the substances monitored, the measurement method used shall enable either continuous measurement with a resolution of approximately one minute (analysers, automatic method), or integrated measurement over a duration of several hours (sampling followed by laboratory analysis, manual method). Depending on the method, the collected data will be processed and presented differently. A database should be developed in accordance with Appendix 6.

For automatic methods based on exploitation of the database, the results shall be presented in the form of four distinct tables for the following periods:

- the entire measurement campaign;
- weekdays;
- weekends;
- peak hours during the week.

Sampling date Stations Lines	**$PM_{2,5}$** (µg/m³)	**PM_{10}** (µg/m³)	**CO_2** (ppm)	**Temperature** (°C)	**Relative humidity** (% RH)
Number of values					
Coverage rate for the scheduled sampling period*					
Average					
Median					
P10 – P90					
(Min – Max)					

* Percentage of quantified measurements among the number of planned measurements.

Additionally, box plots may also be proposed.

For manual methods, based on the exploitation of the database, the results shall be presented in the form of two tables for the following periods:

- weekdays;
- weekends.

Sampling period Stations Lines	PM_{10} (µg/m³)	As (µg/m³)	Ba (µg/m³)	Fe (µg/m³)	Cd (µg/m³)	Cr (µg/m³)	Cu (µg/m³)	Mn (µg/m³)	Ni (µg/m³)	Pb (µg/m³)	Sb (µg/m³)	Zn (µg/m³)
Number of values												
Coverage rate for the scheduled sampling period*												
Average												
Median												
P10 – P90												
(Min – Max)												

*Percentage of quantified measurements among the number of scheduled measurements.

Additionally, box plots may also be proposed.

4.3 Measurements in the rolling stocks

4.3.1. Selection of the rolling stocks to be equipped with instruments

Only those rail lines with rolling stocks circulating underground for over 25% of the total journey time on the rail line are concerned. On these rail lines, measurements will be taken on each type of rolling stock circulating on the line.

4.3.2. Measurement strategy

The rail lines concerned may have several types of routes (Figure 6).

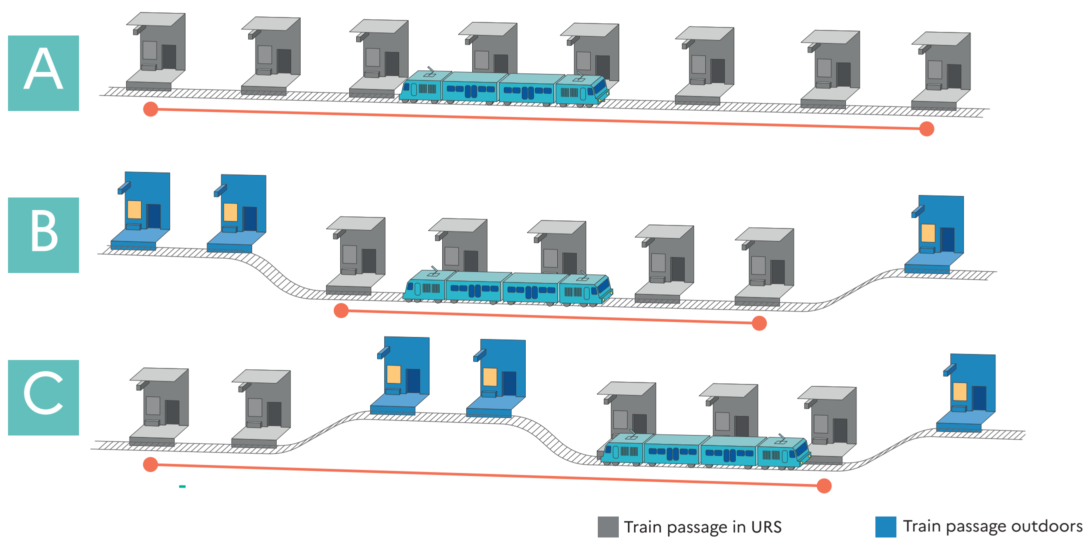


Figure 6: Examples of underground and overground routes

Measurements should be performed from the beginning to the end of the underground section of the rail line being investigated, i.e. from the first to the last underground station on the line (case A and B – Figure 6). In the case of a mixed underground and overground journey (case C – Figure 6), a weighting method is proposed (cf. § 4.3.3) in order to estimate the particle concentration specific to the underground journey (denoted C_{URS}) and the levels of exposure for passengers only travelling these portions.

Locations of measurements

Measurements shall preferably be taken in the middle of the central carriage.

Campaign periods, duration, and frequency

Measurements shall be taken excluding weekends, public holidays, and school holiday periods (rail traffic may be modified) and during peak hours in the morning (between 7 and 9 am) or at the end of the afternoon (between 5 and 7 pm).

Samples should be taken over multiple return journeys along the section of the rail line under investigation to ensure a representative sample of 1 to 2 hours (e.g. 1 outbound trip, 1 return trip, 2 return trips, etc.). Each set of samples shall be taken over three distinct days, whether consecutive or not.

Depending on the size of the network, the entire network shall be covered in one to three years, and shall be renewed in the event of changes of rolling stock.

Measurement methods

Given the difficulty of obtaining power supply in the rolling stock without disturbing traffic and passengers, it is necessary to use autonomous compact equipment.

The proposed methods enable particles to be collected in a filter for the entire journey over the investigated rail line. Deferred analysis (gravimetry and chemical speciation) provide the mass concentration of particles (denoted C_{filter}). In the event that a section of the rail with a mixed underground and overground route (case C), continuous indicative measurements of particle concentrations shall be taken in order to determine particle concentration levels in the rolling stock during the underground and overground journey.

Based on the list of priority substances (P1), the following table presents the measurement systems to be implemented.

Measurement systems implemented		Parameters measured	Duration and frequency of sampling
Principle of the method	**Example of devices**		
Individual autonomous portable particle sampler	HPEM®	PM_{10} $PM_{2,5}$ Métaux sur PM_{10}	**Sampling rate:** 10 L/min. **Duration of sampling:** from 1 to 2 hours that may cumulate several return trips over the route.
Optical indicators for the measurement of airborne dust	Grimm® Dust Trak® FIDAS®	PM_{10} $PM_{2,5}$	**Measurement over the entire route.** **Measurement period:** several seconds to 1 minute
CO_2: Infrared analyser	Q-TRAK® AdvancedSense IAQ® Class'Air®	CO_2	**Measurement over the entire route.** **Measurement period:** several seconds to 1 minute

Tableau 7 : Détail des systèmes de mesure mis en œuvre

Methodological recommendations for particle sampling are provided in Appendix 10 to prevent the alteration of filters during measurement campaigns.

It is recommended that, if possible, the PM_{10} concentration levels measured outdoors during these measurement campaigns be recorded to improve the interpretation of the results of the measurements if an atypical situation is observed in the urban background. The AASQA measurement stations should be representative of the outdoor air of the studied platforms.

4.3.3. Correction of the concentration for mixed routes

If a section of the rail line has mixed underground and overground routes (case C – Figure 6), weighting enables the estimation of the specific particle concentration for the underground route (denoted C_{URS}). This weighting is based on the records of traffic through the URS during sampling, the results of gravimetric measurements of C_{filter} particles and continuous indicative measurements of particles obtained using an optical counter.

A percentage between the levels of concentration in URS (C_{URS}) and overground areas (denoted C_{ext}) is calculated from the averages of concentration levels obtained using an optical counter in these two environments.

The following example illustrates a simplified representation of a temporal graph of particle concentrations provided by an optical counter during a journey on a mixed rail line.

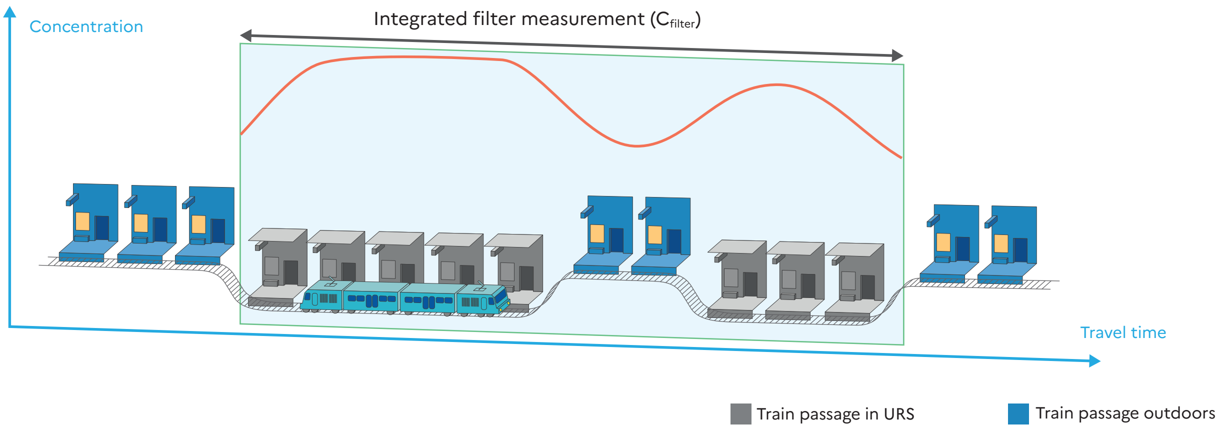


Figure 7: Simplified representation of the change in particle levels over time during a mixed journey along a rail line

The ratio (or percentage) obtained, hereinafter denoted R, is thus equal to: Ratio = C_{URS} / C_{ext}.

$$R = C_{URS} / C_{ext}$$

The weighting calculation is obtained using the following equation:

$$C_{filter} = \frac{(C_{ext} \times duration_{ext}) + (C_{URS} \times duration_{URS})}{duration_{ext} + duration_{URS}}$$

$$C_{filter} = \frac{(C_{URS} / R \times duration_{ext}) + (C_{URS} \times duration_{URS})}{duration_{ext} + duration_{URS}}$$

The particle concentration in URS (C_{URS}) can thus be estimated using these equations. Two examples of determination of particle concentration in URS (C_{URS}) are given in Appendix 8.

4.3.4. Exploitation of the results

A database should be developed in accordance with Appendix 6. For each "rail line/rolling stock", the min-max and average values of the C_{filter} and corrected C_{URS} concentrations shall be calculated. The results should be presented in the form of two tables as follows

C_{filter} in µg/m^3	$PM_{2,5}$	PM_{10}	As	Ba	Fe	Cd	Cr	Cu	Mn	Ni	Pb	Sb	Zn
Number of values													
Cumulative duration of sampling													
Average													
(Min - Max)													

C_{URS} in µg/m^3	$PM_{2,5}$	PM_{10}	As	Ba	Fe	Cd	Cr	Cu	Mn	Ni	Pb	Sb	Zn
Number of values													
Cumulative duration of sampling													
Average													
(Min - Max)													

Regarding the indicative measurements of particle concentrations, the distribution of concentrations measured over the entire route of a rail line (box plot) shall be presented: min-max value, 10 and 90 percentile, median and average, distinguishing between underground and overground journeys.

APPENDIX 1

SUMMARY OF AVAILABLE BIBLIOGRAPHICAL DATA ON AIR QUALITY IN FRENCH URS (COMPILATION OF DATA FROM THE ANSES REPORT AND THE ORS ARTICLE)

Substances	Range of concentrations measured in URS (min-max) (All measurements combined over different periods)	Suspected URS origins	General observations
Particles PM_{10} $PM_{2,5}$	**On platforms:** PM_{10}: from 13 to 1 284 µg/m³ $PM_{2,5}$: from 12 to 626 µg/m³ **In transfer zones:** PM_{10}: from 38 to 101 µg/m³ $PM_{2,5}$: 24 µg/m³		Indoor concentrations are mostly higher than outdoor concentrations. PM concentrations are heterogeneous in space (differences between platforms, rolling stock, corridors, etc.) and time (peak and off-peak hours, night, week/ weekend). PM_{10} are not frequently studied.
Metal (PM speciation) Iron Copper, zinc, antimony, manganese Barium, nickel, chrome, lead (Aluminum, arsenic, calcium, cadmium)	**On platforms:** Iron: from 1,1 to 75 µg/m³ in PM_{10} Copper: from 0,1 to 5,6 µg/m³ in PM_{10} Zinc: from 0,01 to 3,5 µg/m³ in PM_{10} Antimony: from 7,6 to 413 ng/m³ in PM_{10} Manganese: from 19 to 521 ng/m³ in PM_{10}	The main sources of iron- rich particles are braking and abrasion phenomena (Wheel-brake contact, contact between the rolling stock and the electrical power supply, rail-wheel contact). For other metals, the sources are more variable from one network to another. Nevertheless, it seems that the origin of copper could be linked to the electrical power supply system and barium to the braking system. The presence of elements like aluminum, silicon, calcium, potassium, magnesium and titanium is generally attributed to external sources, but in some cases, these elements may have an internal origin such as the wear of construction materials, ballast or the use of abrasives or anti-slip agents, as well as brakes. This depends on the type of rolling stock (age and composition).	Iron is the dominant metallic element, followed by copper, zinc, antimony and manganese.
Crystalline silica (in PM) Asbestos fibers (in PM)	Silica (quartz): from 4 to 113 µg/m³ * Asbestos: less than 20 fibers/L* * Foreign data	The main source of silica is the sand used to increase friction and adhesion during emergency braking or on slopes, as well as the silica is present in the ballast.	Little data is available.

Substances	Range of concentrations measured in URS (min-max) (All measurements combined over different periods)	Suspected URS origins	General observations
PAH 16 PAH (EPA list)	**On platforms:** Benzo(a)pyrene: from 0,05 to 0,52 ng/m^3 **In transfer zones:** Benzo(a)pyrene: from 0,17 ng/m^3		In general, indoor concentrations seem to be related to outdoor concentrations. There is evidence of accumulation and slow degradation of PAH in URS, which may explain why indoor concentrations are slightly higher than outdoor concentrations. ⚠ The majority of the measurements taken concern the particulate phase, with few studies measuring the gaseous phase
MAH Benzene Toluene, Ethylbenzene, Xylenes	**On platforms:** Benzene: from 1,4 to 3,5 µg/m^3 **In transfer zones:** Benzene: 1,9 µg/m^3 **On platforms:** Benzene: from 10 to 27 µg/m^3		Indoor benzene concentrations are slightly higher than outdoor concentrations. The levels observed in URS are less than for other modes of transport (cars, buses). ⚠ The highest concentrations are found in the oldest bibliographical references. The origin was apparently linked to diesel vehicles, the influence of outdoor sources and/or cigarette smoke.
Carbonyl compounds Formaldehyde Acetaldehyde Acetone *Other*	**On platforms:** Formaldehyde: from 2,6 to 6,4 µg/m^3		Indoor concentrations are slightly higher than outdoor concentrations. The principal compound on station platforms is formaldehyde, followed by acetaldehyde and acetone. The concentrations of acetaldehyde and acetone are higher in the rolling stock and are thought to be cause by human metabolism. The levels observed in URS are less than those observed in other modes of transport (cars, buses).

Substances	Range of concentrations measured in URS (min-max) (All measurements combined over different periods)	Suspected URS origins	General observations
CO	**On platforms:** CO : from 0,2 to 0,97 mg/m³	Presence of maintenance work in URS.	Indoor concentrations are mostly lower than outdoor concentrations. Higher indoor concentrations are observed during maintenance work, especially when diesel engines are present.
NOx/NO_2	**On platforms:** NO_2 : from 13 to 65 µg/m³	Presence of diesel vehicles in URS during maintenance work.	Indoor concentrations are lower than or equivalent to outdoor concentrations. NOx is mostly monitored when diesel trains are present (for maintenance).
CO_2	**On platforms:** CO_2 : from 494 to 1 200 ppm		Considered as a confinement indicator.
Particulate carbon EC, OC and BC	**On platforms:** EC : from 4,2 to 16,3 µg/m³ OC : from 6,5 to 9,9 µg/m³ BC : from 2 to 5 µg/m³	According to the authors, the suspected source of BC is the braking system.	In the absence of traffic (at night), indoor concentrations are comparable to outdoor air concentrations. During the day, BC concentrations are higher, suggesting the presence of a source such as braking in the tunnel.

APPENDIX 2

CSHPF NOTE CONCERNING URS AIR QUALITY AND AVAILABLE INDOOR AIR REFERENCE VALUES

Substances (Studied in the bibliography)	**CSHPF note**[14,15,16,17,18,19] **URS indoor air**	**Reference values** **Indoor air** (excluding URS)
Particles PM_{10} $PM_{2,5}$	Hourly monitoring of PM10 Reference values: a function of the outdoor concentration (Cext), the time elapsed and the limit value (V-limit) of the ambient air directive. For a V-limit of 50 µg/m³ and a Cext of 23 µg/m³: T_{und} = 1 h 30 => C_{und} < 455 µg/m³ T_{und} = 1 h 45 => C_{und} < 393 µg/m³ T_{und} = 2 h => C_{und} < 347 µg/m³ T_{und} = 2 h 15 => C_{und} < 311 µg/m³	**HCSP PM_{10} (long-terme)**: Target: 15 µg/m³ annual average Rapid action value: 75 µg/m³ **HCSP $PM_{2,5}$ (long-terme)**: Target: 10 µg/m³ annual average Rapid action value: 50 µg/m³
Metal (PM speciation) Iron (Fe) Copper (Cu), zinc (Zn), antimony (Sb), manganese (Mn) Barium (Ba), nickel (Ni), chrome (Cr), lead (Pb) (Aluminum (Al), arsenic (As), calcium (Ca), cadmium (Cd))	PM_{10} – Metal speciation to better identify the factors that determine these concentrations (Fe, Ni, Cr, Mn, Pb and Cd, As).	
Crystalline silica (in PM) Asbestos fibres (in PM)	PM_{10} – Composition crystalline silica and fibres	Regulatory value Asbestos: 5 f/L
PAH 16 PAH (EPA list)	S9 PAH monitoring Gaseous phase measurement. Fluoranthene, anthracene, phenanthrene and pyrene measurement: measurements over a daily period for "atypical" sites.	**HCSP Naphthalene (long term)**: Benchmark value: 10 µg/m³ Rapid action value: 50 µg/m³ IAQG Naphthalene (long term): 10 µg/m³

14. CSHPF – Note of 5 April 2001 concerning air quality in underground railway areas.
15. CSHPF – Note of 3 May 2001 concerning the development of air quality guidelines for underground railway areas.
16. CSHPF – Note of 8 July 2003 concerning new recommendations for the operators of underground rail networks, RATP in particular.
17. CSHPF – Note of 12 May 2005 concerning new recommendations for operators of underground rail networks concerning pollution on the RATP network.
18. CSHPF – Note of 12 May 2005 concerning new recommendations for operators of underground rail networks, SNCF in particular.
19. CSHPF – Note of 27 September 2006 concerning air quality in transport.

Substances (Studied in the bibliography)	**CSHPF note**[14,15,16,17,18,19] **URS indoor air**	**Reference values** **Indoor air** (excluding URS)
MAH Benzene Toluene, Ethylbenzene, Xylenes	MAH monitoring Toluene measurement: measurements over a daily period for "atypical" sites.	V-guide Benzène (lg-terme): 2 µg/m^3 **HCSP Benzene (long term):** Target value: 2 µg/m^3 Rapid action value: 10 µg/m^3 **DGS (long term):** Short term (1 to 14 d): 30 µg/m^3 Long-terme (14 d to 1 year): 20 µg/m^3 **DGS (lg-terme):** Toluene rapid action value: 300 µg/m^3 Ethylbenzene rapid action value: 1 000 µg/m^3 Xylene rapid action value: 200 µg/m^3
Carbonyl compounds Formaldehyde Acetaldehyde Acetone *Other*		V-guide Formaldehyde (long term): 30 then 10 µg/m^3 in 2023 **HCSP Formaldehyde:** Target value: 10 µg/m^3 Rapid action value: 100 µg/m^3 **IAQG Formaldehyde:** Long term: 10 µg/m^3 annual average Short term: 50 µg/m^3 average 2h **IAQG Acetaldehyde:** Long term: 100 µg/m^3 annual average Short term: 3000 µg/m^3 **IAQG Acrolein:** *Long term: 0.8 µg/m^3 annual average* *Short term: 6.9 µg/m^3 average 1 h*
CO		**IAQG (short term):** 10 mg/m^3 over 8 h 100 mg/m^3 over 15 min
NOx/NO_2	Monitoring NO_2 Hourly NOx monitoring	**IAQG:** Long term: 20 µg/m^3 annual average Short term: 200 µg/m^3 average 1 h
CO_2		**Departmental health regulations:** 1 300 ppm in CO_2 (1 000 ppm with a tolerance of 1 300 ppm for non-smoking premises), fixed values for tertiary buildings.
Particulate carbon EC, OC and BC		

APPENDIX 3

NORMATIVE REFERENCES AND GUIDES

NF EN ISO 16000-1 "Indoor air – Part 1: General aspects of sampling strategy", July 2006.

XP X43-402 "Air quality – Strategy of sampling of chemical pollutants from indoor atmosphere", August 1995.

LCSQA note "Liste des appareils pouvant être utilisés en ASSQA pour la surveillance réglementaire de la qualité de l'air ", updated 29 July 2015.

NF EN 12341 "Ambient air – Standard gravimetric measurement method for the determination of the PM_{10} or $PM_{2.5}$ mass concentration of suspended particulate matter", June 2014.

XP CEN/TS 16450 "Ambient air – Automated measuring systems for the measurement of the concentration of particulate matter (PM_{10}, $PM_{2.5}$)", July 2013.

NF EN 16450 "Ambient air – Automated measuring systems for the measurement of the concentration of particulate matter (PM_{10}, $PM_{2.5}$)", April 2017.

Guidance for the Demonstration of Equivalence of Ambient Air Monitoring Method, January 2010.

LCSQA report "Air intérieur – Indicateurs optiques pour la mesure massique des particules dans les environnements intérieurs", December 2008.

NF EN 14902 "Ambient air quality – Standard method for the measurement of Pb, Cd, As and Ni in the PM_{10} fraction of suspended particulate matter", December 2005.

LCSQA report "Prélèvement et analyse des métaux dans les particules en suspension dans l'air ambiant – 2/2 Guide technique et méthodologique de l'analyse de l'arsenic, cadmium, nickel et plomb dans l'air ambiant", November 2007.

NF EN ISO 16000-7 "Indoor air – Part 7: Sampling strategy for determination of airborne asbestos fibre concentrations", September 2007.

GA X46-033 "Application guide for NF EN ISO 16000-7: Sampling strategy for the determination of airborne asbestos fibre concentrations", August 2012.

NF X43-050 "Air quality – Determination of the asbestos fibre concentration by transmission electron microscopy", January 1996.

NF EN ISO 16000-12 "Indoor air – Sampling strategy for polychlorinated biphenyls (PCBs), polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs) and polycyclic aromatic hydrocarbons (PAHs)", April 2009.

NF EN 15549 "Air quality – Standard method for the measurement of the concentration of Benzo[a]pyrene in ambient air", July 2008.

XP CEN/TS 16645 "Ambient air – Method for the measurement of benz[a]anthracene, benzo[b]fluoranthene, benzo[j]fluoranthene, benzo[k]fluoranthene, dibenz[a,h]anthracene, indeno[1,2,3-cd]pyrene and benzo[ghi]perylene", May 2014.

ISO 12884 "Ambient air – Determination of total (gas and particle-phase) polycyclic aromatic hydrocarbons – Collection on sorbent-backed filters with gas chromatographic/mass spectrometric analyses", April 2000.

- **ISO 16362** "Ambient air – Determination of particle-phase polycyclic aromatic hydrocarbons by high performance liquid chromatography", February 2005.
- **LCSQA report** "Surveillance des PAH – Guide méthodologique pour la surveillance des hydrocarbures aromatiques polycycliques (PAH) dans l'air ambiant et dans les dépôts", 2011.
- **NF EN ISO 16000-5** "Indoor air – Part 5: Sampling strategy for volatile organic compounds (VOCs)", February 2007.
- **NF EN ISO 16000-6** "Indoor air – Part 6: Determination of organic compounds (VVOC, VOC, SVOC) in indoor and test cMAHber air by active sampling on sorbent tubes, thermal desorption and gas chromatography using MS or MS FID", 2012.
- **NF EN ISO 16017-1** "Indoor, ambient and workplace air – Sampling and analysis of volatile organic compounds by sorbent tube/thermal desorption/capillary gas chromatography, Part 1: Pumped sampling", March 2003.
- **NF EN 14662-1** "Ambient air quality – Standard method for measurement of benzene concentrations – Part 1: Pumped sampling followed by thermal desorption and gas chromatography", November 2005.
- **NF EN 14662-2** "Ambient air – Standard method for measurement of benzene concentrations – Part 2: Pumped sampling followed by solvent desorption and gas chromatography", November 2005.
- **NF EN 14662-3** "Ambient air quality – Standard method for measurement of benzene concentrations – Part 3: Automated pumped sampling with in situ gas chromatography", December 2005.
- **LCSQA report** "Guide méthodologique pour la surveillance du benzène dans l'air ambiant", 2014.
- **NF EN ISO 16000-15** "Indoor air – Part 15: Sampling strategy for nitrogen dioxide (NO_2)", April 2009.
- **ISO 6768** "Ambient air – Determination of mass concentration of nitrogen dioxide – Modified Griess-Saltzman method", August 1998.
- **NF EN 14211** "Ambient air – Standard method for the measurement of the concentration of nitrogen dioxide and nitrogen monoxide by chemiluminescence", October 2012.
- **NF EN ISO 16000-26** "Indoor air – Part 26: Sampling strategy for carbon dioxide (CO_2)", October 2012.
- **NF EN 50543** "Electronic portable and transportable apparatus designed to detect and measure carbon dioxide and/or carbon monoxide in indoor ambient air. Requirements and test methods", April 2011.
- **FD CEN/TR 16243** "Ambient air quality – Guide for the measurement of elemental carbon (EC) and organic carbon (OC) deposited on filters", September 2011.

APPENDIX 4

POLLUTANTS OF INTEREST AND RELATED MEASUREMENT METHODS

Pollutants measured	Measurement method	Details of the standard	Examples of sam
Airborne particles (PM) PM_{10} $PM_{2,5}$	**Measurement PM_{10} and/or $PM_{2,5}$:** Method equivalent to the reference method.		TEOM® (FDMS not mandatory)
	PM_{10} measurement: Reference method – Standard NF EN 12341. -> Gravimetric measurement	Nominal sampling duration 24 h +/-1 h Nominal flow rate 2.3 m^3/h (with the possibility of using other sampler-flows mentioned in older versions of standards). Range of application between 1 µg/m^3 and 150 µg/m^3 for PM_{10} and 120 µg/m^3 for $PM_{2.5}$.	DA80®
Metal (PM speciation) Iron (Fe) Copper (Cu), zinc (Zn), antimony (Sb), manganese (Mn) Barium (Ba), nickel (Ni), chrome (Cr), lead (Pb) (Aluminium (Al), arsenic (As), calcium (Ca), cadmium (Cd))	**On PM_{10} filter (from the PM reference method):** NF EN 14902	Measurement in PM_{10} (24 h sampling) Metals concerned: As, Cd, Ni and Pb. Concentration range for the method: As from 0.5 to 350 ng/m^3 Cd from 0.1 to 50 ng/m^3 Ni from 2 to 100 ng/m^3 Pb from 1 to 4000 ng/m^3	DA80® filter
Crystalline silica (in PM) Asbestos fibres	**On PM_{10} filter (from the PM reference method):** Asbestos NF X43-050 (MET).		
PAH 16 PAH (EPA list)	**Particulate and gaseous phase measurements:** ISO 12884 + ISO 16362 (NF EN 15549 + FprCEN/ TS 16645)		Filter + PUF® foam
MAH Benzene Toluene, ethylbenzene, xylenes	**Active sampling:** NF EN ISO 16000-6 + NF EN ISO 16017-1 (Ambient air: NF EN 14662-1 and 2)	50 to 200ml/min **For ambient air:** 24 h sampling Range 0.5 to 50 µg/m^3 Benzene standard volume 10 L	Tube® Carbopack®/
	Analyser: NF EN 14662-3	Range of 0.5 to 100 µg/m^3	GC 5000 BTX® ; VO
	Analyser		Aerolaser® ; MA100-
NOx/NO_2	**Active sampling:** ISO 6768	Range 0.003 to 2 mg/m^3 Sampling from 10 min to 2 h	
	Analyser: Reference method NF EN 14211	Range up to 500 µg/m^3	AC32M® ; A
CO_2	NF EN ISO 16000-26	Choice between an analyser or sampling tube.	
Particulate carbon EC, OC and BC	**On $PM_{2.5}$ filter (from the PM reference method):** CEN/ TR 16243	24 h sampling	DA80® Filter

pling devices/media	Set up on site	
	Advantages	Disadvantages
	Real-time measurement (automatic analyser). Short-term exposure (measurement 1 h and less).	Bulky device and constraints for installation/use. Does not enable chemical speciation.
Partisol®	Filter sampling with the possibility of performing chemical speciation.	Bulky device and constraints for installation/use. Deferred measurement. Long-term exposure Measurement of a single fraction (PM_{10} or $PM_{2.5}$).
	Associate with PM measurements.	Deferred measurement. Long-term exposure.
	Associate with PM measurements (for the particulate phase).	Constraints on installation/use.
Carbograph®	Compact and easy to set up. Short-term exposure (measurement 1 to a few hours).	Deferred measurement. Constraints on installation/use.
C72M® ; AirToxic GC 866®	Real-time measurement (automatic analyser). Very short-term exposure (measurement 15 min).	Bulky device and constraints for installation/use.
Méthanalyser® ; Interscan®	Real-time measurement (automatic analyser). Very short-term exposure (measurement 15 min).	Device +/- footprint and +/- constraints for installation/use.
	Compact and easy to set up. Short-term exposure (measurement 1 to a few hours).	Deferred measurement. Constraints on installation/use.
API 200E® ; TEI 42i®	Real-time measurement (automatic analyser). Very short-term exposure (measurement over a few minutes).	Bulky device and constraints for installation/use.
	Associate with PM measurements.	Deferred measurement. Long-term exposure (measurement over 24 h).

APPENDIX 5

MINIMUM QUALITY PARAMETERS TO RECORD

Characteristics of the rolling stock

Date (DD/MM/YY)	**Line**	**Type of rolling stock** (underground, RER, tram, etc.)	**Model**	**Compartmentalised rolling stock** (yes/ no)	**Air-conditioned equipment** (yes/ no)	**Number of decks** (single/ double)	**Maximum weight of the rolling stock including passengers** (in tonnes)	**Power source** (rails or catenaries)	**Wheels** (tyres/iron)	**Braking system** (electrodynamic/ mechanical braking)	**Braking materials**

Passenger traffic/conditions of circulation

Date (DD/MM/YY)	**Line**	**Station**	**Disturbances during measurements** (yes/ no) **If yes: unplanned stoppages, unscheduled works, etc.**	**Passenger rate during peak hours** (number of passengers per hour)	**Passenger rate during off-peak hours** (number of passengers per hour)

Platform characteristics

Date (DD/MM/YY)	**Line**	**Station**	**Depth of the station** (in metres)	**Volume of the station** (in cubic metres)	**Platform screen doors** (yes/ no)	**Type of ventilation** (natural/ mechanical) **If mechanical: maintenance** (yes/ no) **and flow rate** (in m^3/h)	**Connections** (yes/no) **If yes: on the same platforms/on different platforms** (overlapping lines)	**Outdoor sources identified** (road junction/ underground parking/ construction sites, etc.)	**Number of tracks at the platform**

APPENDIX 6

DATABASE REPORTING OF MEASUREMENT RESULTS

Platform measurements – Filter sampling of airborne dust and deferred filter analysis (1 line per daily measurement)

Station	**Line**	**Location of the sampling system** (centre of the platform, other: specify)	**Height of sampling** (in metres)	**Date** (DD/MM/YY)	**Time at the start of sampling** (HH/MM)	**Time at the end of sampling** (HH/MM)	**PM_{10}** ($\mu g/m^3$)	**$PM_{2.5}$** ($\mu g/m^3$)	**As** ($\mu g/m^3$)	**	**Zn** ($\mu g/m^3$)
							*	*			*

*To facilitate interpretation, use a results code with "0 for measurement not taken", "1 for result below QL", and "2 for quantifiable result".
**Results of analyses of other metals should also be indicated in this table in the following order: Ba, Fe, Cd, Cr, Cu, Mn, Ni, Pb, Sb.

Platform measurements – Automatic analyser for airborne dust and continuous measurements of comfort parameters (1 line per quarter-hourly measurement)

Station	**Line**	**Location of the sampling system** (centre of the platform, other: specify)	**Height of sampling** (in metres)	**Date** (JJ/MM/AA)	**Time** (HH/MM)	**PM_{10}** ($\mu g/m^3$)	**$PM_{2,5}$** ($\mu g/m^3$)	**CO_2** (ppm)	**Temperature** (°C)	**Relative humidity** (% HR)
						*				

*To facilitate interpretation, use a results code with "0 for measurement not taken", "1 for result below QL", and "2 for quantifiable result".

Measurements in rolling stock– Filter sampling of airborne dust and deferred filter analysis

Line	**Location of the sampling system** (centre of the train, on the top deck in the case of a double-decker train, etc.)	**Height of sampling** (in metres)	**Date** (DD/MM/YY)	**Time at the start of sampling** (HH/MM)	**Time at the end of sampling** (HH/MM)	**Journey** (1 outbound trip, 1 return trip, 2 return trips, etc.)	**C_{filter} PM_{10}** ($\mu g/m^3$)	**C_{filter} $PM_{2,5}$** ($\mu g/m^3$)	**C_{filter} As** ($\mu g/m^3$)	**	**C_{filter} Zn** ($\mu g/m^3$)	**C_{EFS} PM_{10}** ($\mu g/m^3$)	**C_{EFS} $PM_{2,5}$** ($\mu g/m^3$)	**C_{EFS} As** ($\mu g/m^3$)	**	**C_{EFS} Zn** ($\mu g/m^3$)
							*	*	*		*	*	*	*		*

*To facilitate interpretation, use a result code with "0 for measurement not taken", "1 for result below QL", and "2 for quantifiable result".
**Results of analyses of other metals should also be indicated in this table in the following order: Ba, Fe, Cd, Cr, Cu, Mn, Ni, Pb, Sb.

APPENDIX 7

METAL QUANTIFICATION LIMITS

Platform measurements –
Filter sampling of airborne dust and deferred filter analysis

PM_{10} (µg/m³)	As (µg/m³)	Ba (µg/m³)	Fe (µg/m³)	Cd (µg/m³)	Cr (µg/m³)	Cu (µg/m³)	Mn (µg/m³)	Ni (µg/m³)	Pb (µg/m³)	Sb (µg/m³)	Zn (µg/m³)
10	0,0001 – 0,001*	0,0001 – 0,001	0,0001 – 0,001	0,0001 – 0,001	0,0001 – 0,001	0,0001 – 0,001	0,0001 – 0,001	0,0001 – 0,001	0,0001 – 0,001	0,0001 – 0,001	0,0001 – 0,001

* The quantification limit varies according to the flow rate of the sampler used; these QL have been calculated for sampling flow rates between 30 m³/h and 2.3 m³/h.

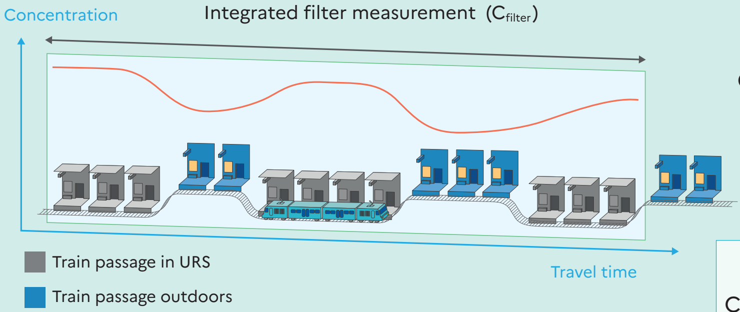
Measurements in rolling stock –
Filter sampling of airborne dust and deferred filter analysis

As (µg/m³)	Ba (µg/m³)	Fe (µg/m³)	Cd (µg/m³)	Cr (µg/m³)	Cu (µg/m³)	Mn (µg/m³)	Ni (µg/m³)	Pb (µg/m³)	Sb (µg/m³)	Zn (µg/m³)
0,04 – 0,08**	0,04 – 0,08	0,04 – 0,08	0,04 – 0,08	0,04 – 0,08	0,04 – 0,08	0,04 – 0,08	0,04 – 0,08	0,04 – 0,08	0,04 – 0,08	0,04 – 0,08

** The quantification limit varies according to the sampling period; these QL have been calculated for sampling periods varying from 1 to 2 hours.

APPENDIX 8

SIMPLIFIED NUMERICAL EXAMPLE TO ESTIMATE PARTICLE CONCENTRATION IN URS (C_{URS}) ON ROLLING STOCK



$$C_{filter} = \frac{(C_{ext} \times duration_{ext}) + (C_{URS} \times duration_{URS})}{duration_{ext} + duration_{URS}}$$

So, $R = C_{URS} / C_{ext}$

$$C_{filter} = \frac{(C_{URS} / R \times duration_{ext}) + (C_{URS} \times duration_{URS})}{duration_{ext} + duration_{URS}}$$

Numerical example:

Information obtained via optical counter: factor 7 between the averages of URS and outdoor concentrations.

$C_{ext} = C_{urs} / 7$

Information obtained from the integrated filter measurement over the entire line: $C_{filter} = 70\,\mu g/m^3$

$$\rightarrow \quad C_{filter} = 70 = \frac{(C_{ext} \times 5) + (C_{URS} \times 10)}{5 + 10} = \frac{(C_{URS} / 7 \times 5) + (C_{URS} \times 10)}{5 + 10}$$

$\rightarrow \quad C_{URS} = 1050 / 10{,}7 = 98\,\mu g/m^3$

APPENDIX 9

RESULTS OF THE MEASUREMENTS OF TESTS CONDUCTED WITH VARIOUS RAIL OPERATORS

Example No 2:

A trials campaign steering committee, the CPCE, was established. It brought together four French rail operators, Ineris, the Ministry of Health and the Ministry of the Environment, who chaired it. The goal of the CPCE was to carry out trials to test several parts of the guide and clarify its implementation.

Three trials were thus conducted in 2017. At least two rail operators participated in each trial.

The goal of trial No. 1 was to assess the methodology for ranking platforms based on indicative measurements of particle and CO_2 concentrations. These one-off 15-minute measurements were performed at least twice per platform on two different days in order to obtain a sufficient data set. In addition, quality parameters were recorded, including descriptions of public-access spaces, passenger traffic and rolling stock.

The aim of trial No. 2 was to assess the proposed methodologies for measuring parameters on underground platforms and to determine the associated quantification limits.

The objective of trial No. 3 was to evaluate the recommendations regarding the measurements to be taken in rolling stock and to assess whether the results of the particle measurements are quantifiable and to determine the associated quantification limits.

The results of the measurements taken on the networks that participated in these trials were anonymised and aggregated. They are presented below.

Trial No. 1: Platform ranking

The averages of the indicative measurements of PM_{10} particles taken on 92 platforms are ranked in the following graph on the basis of 159 measurement results.

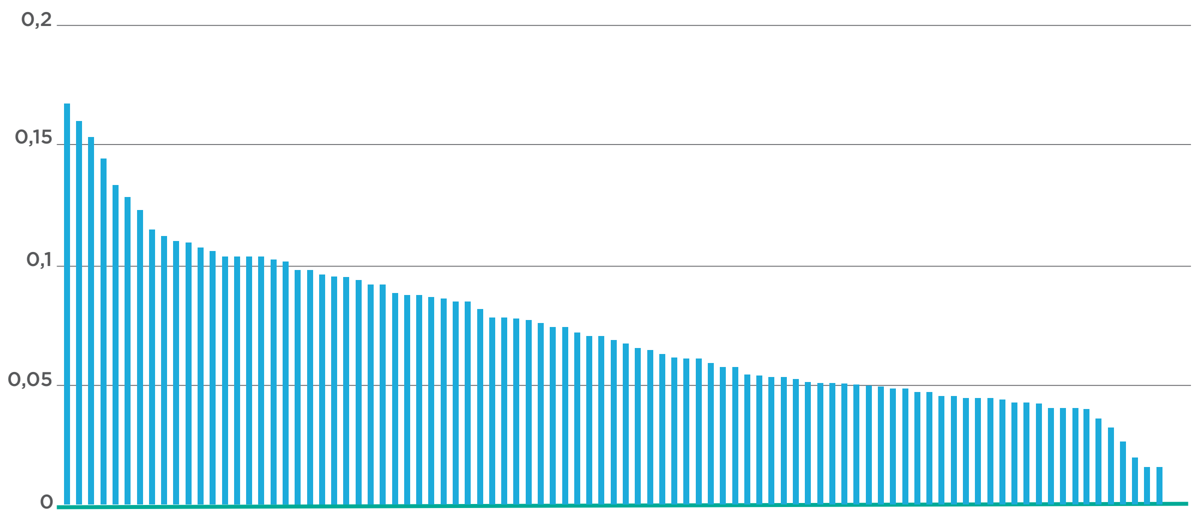


Figure 8: Ranking of the 92 platforms on which PM_{10} were measured (results in mg/m^3)

The average of the indicative measurements of CO_2 conducted on 70 platforms are ranked in the following graph based on 140 measurement results.

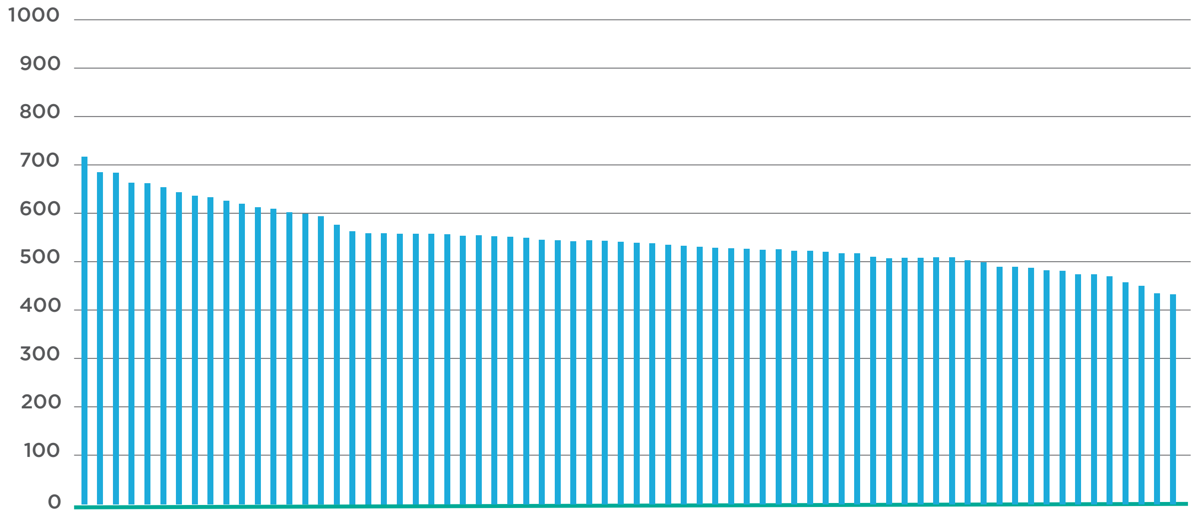


Figure 9: Ranking of the 70 platforms on which CO_2 was measured (results in ppm)

Variability was observed in the results from one measurement to another for the same platform. This is why this guide recommends that measurements be taken over several days. On average, at least three measurements of PM_{10} particles must be taken over different days for each platform studied.

Trial No. 2: "Platform" locations

In the tables below the average measured concentrations of PM, CO_2 and metals are presented in an anonymised and aggregated way for all the networks participating in this trial.

	$PM_{2,5}$ (µg/m³)	**PM_{10}** (µg/m³)	**CO_2** (ppm)
Average	44	89	464
(Min - Max)	(0 – 448)	(5,2 – 309)	(152 – 847)

Table 7: Results of the measurements obtained by automatic airborne dust analyser and by infrared analyser for CO_2 over two consecutive weeks

	PM_{10}	**As**	**Ba**	**Fe**	**Cd**	**Cr**
Number of samples	39	39	14	39	25	39
Average	113	0,010	1,37	36,6	0,001	0,16
(Min – Max)	(28 – 285)	(0,003 – 0,185)	(1,09 – 1,87)	(5,2 – 105,0)	(0,0003 – 0,0010)	(0,03 – 0,30)

	Cu	**Mn**	**Ni**	**Pb**	**Sb**	**Zn**
Number of samples	39	39	39	39	25	39
Average	1,13	0,57	0,04	0,08	0,004	1,03
(Min – Max)	(0,19 – 2,86)	(0,05 – 4,33)	(0,006 – 0,093)	(0,01 – 0,68)	(0,003 – 0,006)	(0,21 – 5,17)

Table 8: Results of the measurements obtained by filter sampling of airborne dust and metals and deferred filter analysis (results in µg/m³)

Sampling and analyses were conducted by different laboratories. The quantification limits for metals can vary from 0.7 ng/m^3 (for metals like arsenic (As), cadmium (Cd), copper (Cu) and lead (Pb)) to 8 ng/m^3 (in the case of iron (Fe)).

The average distribution of metal elements measured on platforms is presented in the following figure.

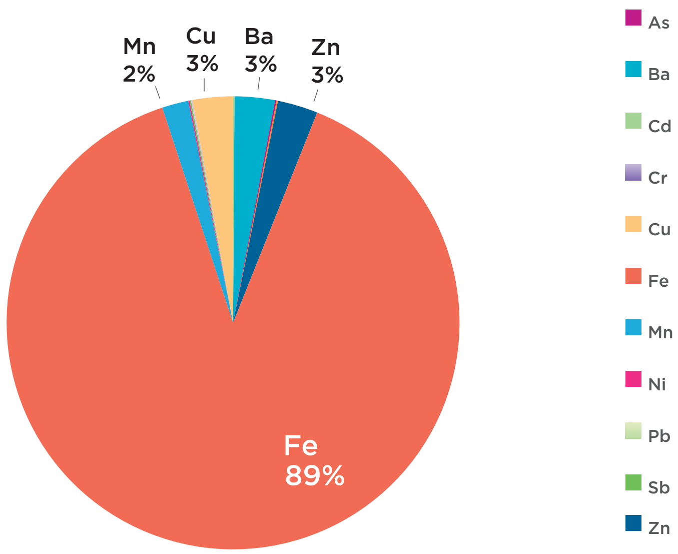


Figure 10: Distribution of metals present in the air on URS platforms

Trial No. 3: "Rail Rolling stock" locations

For measurements taken aboard trains during 1 to 2 h of sampling (return trip/2 return trips) using a personal impactor at 10 L/min, the following concentrations were measured:

	$PM_{2,5}$	PM_{10}
Number of samples	7	7
Average	102,8	145,4
(Min – Max)	(36,0 – 164,5)	(58,0 – 251,0)

Table 9: Results of particle concentrations measured on rolling stock (results in µg/m^3)

These measurements made it possible to quantify the airborne particles in moving rolling stock over an entire line.

The average concentrations of metals measured are presented in the tables below.

As	Ba	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Sb	Zn
Average concentration measured on trains in µg/m³										
<LQ	0,8	<LQ	0,3	<LQ	3,8	<LQ	<LQ	0,9	<LQ	0,5
<LQ	5,1	<LQ	0,4	4,5	48,0	0,5	0,4	<LQ	<LQ	2,4
<LQ	3,9	<LQ	0,3	2,7	33,6	0,4	0,4	0,8	<LQ	1,9
<LQ	6,4	<LQ	0,5	9,3	61,4	0,8	0,4	1,1	<LQ	7,2
<LQ	4,1	<LQ	0,3	4,0	36,1	0,4	<LQ	0,5	<LQ	2,1
<LQ	5,8	<LQ	0,9	4,3	50,6	0,7	0,7	<LQ	<LQ	3,0
<LQ	5,0	<LQ	0,8	2,8	40,3	0,6	<LQ	<LQ	<LQ	2,3

Table 10: Results for airborne metals measured in trains over an entire line

	As	Ba	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Sb	Zn
Average concentration in µg/m³	<LQ	5,07	<LQ	0,52	4,58	44,99	0,58	0,49	0,80	<LQ	3,15

QL = 80 ng/m³ (for 1 hour of sampling) or 40 ng/m³ (for 2 hours of sampling).

Most metals are quantifiable using this sampling method.

The average distribution of metal elements measured on a rail operator's trains is presented in the following figure.

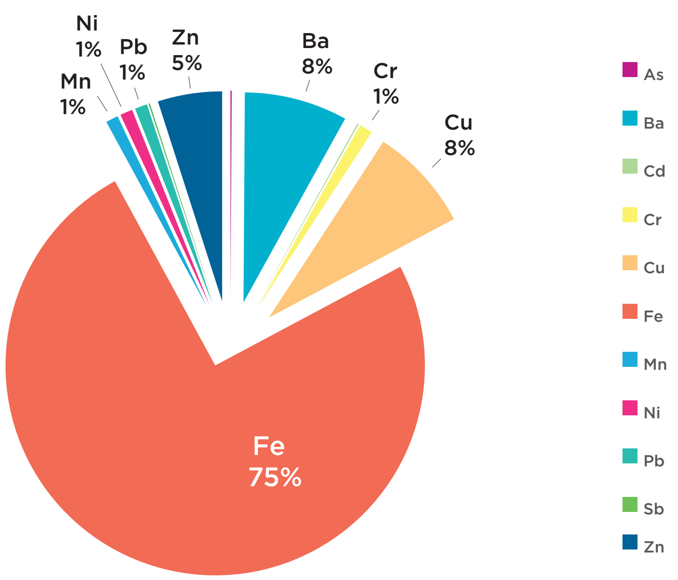


Figure 11: Average distribution of metals measured in the rolling stock

APPENDIX 10

METHODOLOGICAL RECOMMENDATION FOR THE USE OF AUTONOMOUS PERSONAL SAMPLERS FOR MEASUREMENTS ON ROLLING STOCK

During steering committee (COPIL) meetings, the rail operators provided their feedback on the implementation of harmonised air quality (IAQ) measurements in URS in compliance with the guidelines. Some operators have identified an issue related to the use of portable autonomous particle filter samplers during measurements on rolling stocks. A working group was established in 2022 with the specific objective of addressing this matter.

Deterioration of the filters by "tearing" or "flaking" has been observed by some operators when tightening the device. Tests were therefore conducted at Ineris to clarify the sampling protocol in order to limit this phenomenon.

Summary of the issue

The filters of the autonomous portable samplers recommended for measurements aboard rolling stocks are retained by tightening metal parts directly onto the filter. The purpose of this type of tightening system is to ensure that the filter is mechanically retained, and the system is sealed. Given the different nature of the materials that come into contact with each other, excessive or unequal tightening of the various points of attachment can lead to tearing or flaking of the filters, as illustrated in the Figure 12. This deterioration leads to losses of mass in the filters, thus invalidating the sample.

Proposed solution

The solution adopted by the working group involved using the seals offered by the sampling system manufacturers and tightening using a torque wrench.

A torque wrench is a tool that enables nuts and bolts to be tightened to a precise torque to ensure that they are fitted in an optimal manner. Tightening to a precise torque makes it possible to: (i) limit the mechanical force applied to the filter and consequently any weakening of the filter, and (ii) apply consistently precise torque settings thereby limiting unequal tightening of the various points of attachment. The operating principle of torque wrenches is based on the presence of a mechanical or electronic release mechanism. When using the wrench, a release signal (e.g. a mechanical "click", vibrations, visual signal, etc.) is given when the preset torque value is reached. The wrench resets automatically and is once again ready for use. The torque is selected using either a vernier scale or a digital display, depending on the chosen technology.

In the context of the work conducted, the accepted torque ranges for any type of filter suitable for the sampling of metals in underground railway areas are:
- 22–23 cN.m without a seal;
- 21–22 cN.m with a seal.

* *cN.m: centinewton metres*

Filter deteriorated by tearing — Filter deteriorated by flaking

Figure 12: Illustration of damaged filters when using portable samplers.

6 ABBREVIATIONS, INITIALISMS AND ACRONYMSS

AASQA: Association Agréée de Surveillance de la Qualité de l'Air (French approved air quality monitoring associations)

ANSES: Agence Nationale de Sécurité sanitaire de l'alimentation, de l'environnement et du travail (Agency for Food, Environnemental and Occupational Health & Safety)

BC: Black Carbon

BTEX: Benzene, Toluene, Ethylbenzene, Xylenes

CO: Carbon monoxide CO_2: Carbon dioxide

CSHPF: Conseil Supérieur d'Hygiène Publique de France (French Higher Council for Public Hygiene)

DGS: Direction Générale de la Santé (Directorate General for Health)

EC: Elemental carbon

URS: Underground railway stations

EPA: Environmental Protection Agency

PAB: Public-Access Buildings

PAH: Polycyclic Aromatic Hydrocarbons

HCSP: Haut Conseil de la Santé Publique (French High Council for Public Health)

RH: Relative humidity

Ineris: Institut national de l'environnement industriel et des risques (French National Institute for Industrial Environment and Risks)

NO: Nitric Oxide

NO^2: Nitrous Oxide NOx: Nitrogen Oxides OC: Organic Carbon

ORS: Observatoire régional de santé (Regional Health Observatory)

PM_{10}: Particulate Matter with a median aerodynamic diameter of less than 10 µm

$PM_{2.5}$: Particulate Matter with a median aerodynamic diameter of less than 2.5 µm AAQ: Ambient Air Quality

IAQ: Indoor Air Quality

RATP: Régie autonome des transports parisiens (Paris transport authority)

RER: Réseau Express Régional (French regional express rail network)

SNCF: Société Nationale des Chemins de Fer français (French national rail company)

T°C: Temperature

RAV: Rapid Action Value

V-target: Target Value

IAQG: Indoor Air Quality Guidelines

V-limit: Limit value BM: Benchmark value Vref: Reference value

This guide provides recommendations for carrying out harmonized air quality measurements within underground railway areas (URA). The main purpose of this guide is to acquire data on the air pollution levels that can be observed in URAs, based on a common approach agreed by a working group chaired by the Ministry of Ecological Transition and Territorial Cohesion, and including several rail operators, organizing authorities, ministries and Ineris.

The measurements cover the air in underground railways platforms and rolling stock. They aim to characterize the concentration levels of certain pollutants to which passengers are exposed, mainly PM_{10} and $PM_{2.5}$ particles, and the metals present in PM_{10} particles. The measurement of CO_2 has also been incorporated into the sampling plan as a confinement indicator in relation to air renewal, temperature and relative humidity (to identify atypical situations in terms of passenger comfort).

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